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RESEARCH MEMORANDUM

AN ANALYSIS OF AIRSPEEDS AND MACH NUMBERS ATTAINED BY

LOCKHEED CONSTELLATION AIRPLANES IN TRANSCONTINENTAL

OPERATIONS DURING THE EARLY SUMMER OF 1946

By

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

Airspeed and altitude data obtained from Lockheed Constellation
airplanes flying between New York and San Francisco during May and
June of 1946 have been analyzed to determine the probability of
reaching or exceeding given values of airspeed and Mach number. The
analysis indicated that for the data obtained during these flights
the total probability of exceeding the placard "never-exceed" speed
depends principally on the probability of exceeding this speed in
descent. On the average, the placard speed may be exceeded on the
order of once in every 100 hours of descent, or on the order of
once in every 1000 hours of total flight time. The analysis also
indicated that the probability of exceeding the critical Mach number
is negligible at the altitudes flown, which were less than 20,000 feet.

INTRODUCTION

At a meeting of the NACA Committee on Aerodynamics held
March 12, 1946, concern was expressed about the possibility of
inadvertently attaining excessive airspeeds and Mach numbers on
large aerodynamically clean transport airplanes. Accordingly, the
National Advisory Committee for Aeronautics, in cooperation with
the Civil Aeronautics Administration and Pan American Airways,
obtained samples of data on Lockheed Constellation airplanes during
several round-trip flights between New York and London and between
New York and Bermuda. The results of an analysis of these samples
have been published in reference 1.

In order to obtain similar data on the same type of airplane
operating on transcontinental routes, the CAA arranged to have
Army flight analyzers installed on the Lockheed Constellations of
several airlines. The first data from these installations have been

obtained from operations on Transcontinental and Western Airlines
between New York City and San Francisco during May and June 1946.
These data, which consisted basically of continuous time histories
of airspeed and altitude, have been analyzed statistically to
determine the probability of reaching or exceeding various values
of airspeed and Mach number during different flight conditions.

APPARATUS AND TEST CONDITIONS

Two Lockheed Constellation airplanes, operated by Trans-
continental and Western Airlines, were used in the present investi-
gation. The characteristics of these airplanes are given in table I.
The values of 324 miles per hour for the placard "never-exceed"
speed and 0.65 for the critical Mach number were obtained from a
representative of CAA. The value of critical Mach number was stated
to have been based on wind-tunnel tests. It may also be noted
that V_g, the design gliding speed, for these airplanes is 360 miles
per hour. The average take-off and landing gross weights, together
with the maximum variations in these quantities, are given in table II.

Hathaway flight analyzers with a record speed of approxi-
mately $\frac{3}{8}$-inch per minute were installed in each airplane. Since
timers were not used with the instruments, the time scale was
determined from notes made by an observer. The flights analyzed
were made between New York and San Francisco and between New York
and Chicago or Kansas City. The total flight time of records
analyzed herein is 130 hours. The average time for the round trip
to San Francisco was 21 hours. An average of six landings (or six
flights) were made per round trip although the actual number varied
from four to seven. The flights varied in length from $1\frac{1}{4}$ to $7\frac{1}{4}$ hours
with an average length of 3 hours. The average time for the round
trips to Kansas City and Chicago were 9 and 6 hours, respectively.
Two flights were made on each Chicago trip and two to four flights
were made on each Kansas City trip. The breakdown of flight time
according to the operating conditions of climb, level flight, descent,
and landing approach for the various routes is given in table III.

The operating altitude ranged between 4000-and 20,000-foot
pressure altitude although approximately 70 percent of the flight
time was spent between 14,000-and 18,000-foot altitude.

General information on the weather conditions during these
flights was lacking. Inspection of simultaneously recorded
accelerations indicated about the normal amount of turbulence for

transport operations. In addition, the information supplied with
the records did not indicate any unusual weather. It may be assumed,
therefore, that the weather was average for May and June.

EVALUATION OF DATA AND RESULTS

For convenience in the statistical analysis, each flight was
divided into four parts - climb, level flight, descent, and landing
approaches. The airspeeds and Mach numbers considered in each of
these categories are not only those attained while the airplane is
in the ideal attitude associated with that category, but are also
those which are attained inadvertently for any of several causes
while the pilot is attempting to maintain an ideal condition. The
data on landing approaches were not treated in the analysis since
it was considered unlikely that excessive speeds would be attained
during this flight attitude. The records showed a continual reduc-
tion in airspeed from the descent airspeed to the landing speed.

For each condition, the maximum airspeed and Mach number were
determined during each 6 minutes of flight. All values of airspeed
are the computed equivalent airspeed $V\sqrt{\rho/\rho_0}$ without a correction
for the installation error. The maximum Mach number in each
interval was obtained by selecting, within each interval, airspeed-
altitude combinations which would lead to the larger values of Mach
number and then selecting the largest Mach number computed from
these combinations. The frequency distributions of maximum airspeed
and maximum Mach number for each of the three flight conditions are
shown in tables IV and V, respectively.

Standard statistical methods were employed to fit Pearson
type III probability curves (reference 2) to each of the frequency
distributions in tables IV and V. Within appropriate limits, these
probability curves, which are shown in figures 1 and 2, give the
probability that the airspeed or Mach number in any 6-minute
interval of climb, level flight, or descent will attain or exceed
a given value.

For ease in interpreting the results, probability curves have
been referred to a time scale in the following manner. If P is
the probability that a given value of airspeed or Mach number will
be exceeded, on the average, once in a 6-minute interval, then that
value will be exceeded, on the average, once in each $1/P$ interval,
or once in each $1/10 P$ hours of flight. Using this conversion

factor the average number of hours of flight to exceed given values
of airspeed and Mach number have been determined and the results
are shown in figures 3 and 4, respectively.

PRECISION

The major errors in the values of airspeed and Mach number in
this investigation may be attributed to the inaccuracy in reading
the records, the installation error, and the instrument error. The
records could be read to $\pm 2\frac{1}{2}$ miles per hour at low speeds (200 miles
per hour or less), ± 1 mile per hour at high airspeed (greater than
200 miles per hour), and to ± 500-foot pressure altitude. The
corresponding reading errors for both the airspeed and Mach number
ranged from about ± 2 percent at an airspeed of 164 miles per hour
and a Mach number of 0.23 to ± 1 percent at 318 miles per hour
and 0.53. The installation error, which was not corrected in the
analysis, was negligible up to 220 miles per hour but increased to
about 2 percent at 324 miles per hour. The instrument error was
corrected by the use of the instrument calibration curves. The
combined errors in the values of airspeed and Mach number presented
will, therefore, not exceed 2 percent for the lower values or 3 per-
cent at the higher values.

DISCUSSION

The interpretation, by means of statistical analysis, of such
data as are presented herein should be made with appreciation of
certain practical considerations not specifically treated in the
analysis. Without violating this precaution, it may be said that
the data disclose several facts: First, as can be observed by
examination of figures 1 and 2, the probability of reaching or
exceeding the never-exceed speed is substantially greater than the
probability of reaching or exceeding the critical Mach number;
second, the probability of reaching or exceeding the never-exceed
speed in descent is substantially greater than the corresponding
probability in climb or level flight; and third, the results are
sufficiently similar to the results reported in reference 1 as to
indicate that the rather high probability of attaining the greater
values of airspeed is essentially due to the high performance
qualities of modern transport airplanes.

Because of the relative importance of the probability of
reaching or exceeding the never-exceed speed in descent, the
numerical value of this probability is of considerable interest.
This probability, expressed in terms of time, is shown by figure 3
to be about 115 hours of descent time per occasion, but the total
flight time per occasion is of greater significance. This latter
value, strictly speaking, depends upon the combined influence of
the operating conditions of climb, level flight, and descent. How-
ever, the probabilities of exceeding the never-exceed speed in climb
or level flight are so small that they would not be expected to
influence the total flight time per occasion to any considerable
degree. An analysis of the combined probabilities, based on the
assumption that the probability curves for climb and level flight
are still valid when extrapolated to the never-exceed speed, showed
that the total time per occasion was within 4 percent of the total
time based simply on division of the time per occasion in descent
by the "descent ratio," or ratio of flight time spent in descent to
total flight time. In view of this small effect, of the uncertainties
in the extrapolations, and of the fact that only "order-of-magnitude"
effects are of interest, the total time per occasion can be deter-
mined with sufficient accuracy by the simple direct application of
the descent ratio.

The descent ratio can be seen from table III to vary between
8 percent and 15 percent for the various routes considered in this
sample. Over this range of values the total flight time required
to reach or exceed the never-exceed speed is shown in figure 5,
from which it appears that the total time is of the order of 1000 hours
per occasion - indicating a rather frequent occurrence.

It may be noted in figure 1 that none of the experimental points
on the descent curve actually exceed the never-exceed speed. The
question of the validity of extrapolation of the data to or beyond
the never-exceed speed therefore naturally arises. Of course, a
probability analysis such as has been made here provides a mathe-
matical basis for such extrapolation, but the extrapolation will be
valid only if the laws governing the data combine to follow the
mathematical function throughout the range of extrapolation. In
the present instance there may be some possibility that the laws
governing the data will change beyond the present limits of the data
because of the never-exceed speed placard which warns the pilot to
take appropriate action to avoid higher speeds. However, it seems
reasonable to suppose that speed increments above those values
required for reasonable operation under ideal conditions are the
result of inadvertencies or unusual operational demands. The
existence of such inadvertencies under practical flying conditions
removes complete control of the airspeed from the will of the pilot,

and it follows, therefore, that the data for descent will follow a substantially continuous function even through the placard speed. There is no doubt that, in general, the existence of a speed placard does not prevent the placard speed from being exceeded because a great deal of V-G data are available to verify this point. It is reasonable, therefore, to accept at face value the extrapolated values of probability for descent through the placard speed to some unknown point beyond that speed. Accordingly, it is reasonable to say that the data show that, on the average, the placard speed may or will be reached or exceeded a given number of times, or that this speed may or will be reached or exceeded once in a given number of hours of flying.

Because the data were taken under more or less normal weather conditions, the airplane was at no time upset by severe turbulence to such a degree that it was caused to spin or dive at steep angles. Insofar as there is a certain small probability of such an upset, a point or region is eventually reached where discontinuity in the data may be expected if sufficiently large quantities of data are obtained. Owing to the extremely small value of this probability, the region of discontinuity must obviously lie well beyond the placard speed and have no bearing on the significance of the present results for descent to and somewhat beyond the placard speed. In any event, beyond such point as the upset condition affects the result, the speeds will be greater for given probabilities than given by the present curve.

Extrapolation of the climb and level-flight curves to the placard speed is not considered to be justified in view of the large gap between the highest speeds recorded in these conditions and the placard speed. As previously noted, however, the probability of attaining excessive speeds in either of these conditions is sufficiently remote that the essential significance of the data is not materially affected by such probability.

Attention should, perhaps, be directed again to the fact that the present data apply to operations at altitudes less than 20,000 feet. Operations at higher altitudes will change the relationship between probability of exceeding the critical Mach number and probability of exceeding the placard speed so that the former value will become of greater importance relative to its present value.

CONCLUSIONS

Analysis of airspeed and altitude data obtained at less than 20,000 feet altitude from Lockheed Constellation airplanes operated by Transcontinental and Western Airlines between New York and Chicago, New York and Kansas City, and New York and San Francisco during the early summer of 1946 has indicated the following conclusions:

1. The probability of reaching or exceeding the never-exceed speed is substantially greater than the probability of reaching or exceeding the critical Mach number.

2. The probability of exceeding the critical Mach number is apparently negligible.

3. The probability of reaching or exceeding the "never-exceed" speed in descent is so much greater than in level flight or climb that descent is apparently the only condition of importance.

4. The never-exceed speed of 324 miles per hour will probably be exceeded, on the average, once in the order of 100 hours of descent or once in the order of 1000 hours of total flying time.

5. While some significant differences may exist between the present results and corresponding results previously obtained over ocean routes on another airline, the two results are of the same order and sufficiently similar to indicate that the high probability of attaining the greater values of airspeed is essentially due to the high performance qualities of modern transport airplanes.

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8 NACA RM No. L7C06

REFERENCES

1. Steiner, Roy., and Peiser, A. M.: An Analysis of Airspeeds and
   Mach Numbers Attained by Lockheed Constellation Airplanes in
   Trans-Atlantic Operation during the Spring of 1946.
   NACA MR No. L6G09a, 1946.

2. Peiser, A. M., and Wilkerson, M.: A Method of Analysis of
   V-G Records from Transport Operations. NACA ARR No. L5J04,
   1945.

TABLE I

CHARACTERISTICS OF LOCKHEED CONSTELLATION AIRPLANE

Gross weight, lb, design take-off 90,000
Wing area, sq ft, value used in design   1,650
Wing span, ft   123
Mean aerodynamic chord, ft 14.67
Slope of lift curve, per radian (value used to calculate
    gust load factor) 4.67
Maximum indicated airspeed in level flight, mph,
    (any altitude)   271
Placard "never-exceed" speed, mph   324
Critical Mach number (wind-tunnel value) 0.65

TABLE II

GROSS WEIGHTS DURING FLIGHT TESTS

Gross weight, lb, average, take-off 78,041
Maximum variations from average gross weight, lb,
    take-off . . . . $\begin{cases} 10,359 \\ -9,904 \end{cases}$
Gross weight, lb, average, landing 70,780
Maximum variations from average gross weight, lb,
    landing . . . . $\begin{cases} 6,186 \\ -7,354 \end{cases}$

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TABLE III

PERCENT OF TOTAL FLIGHT TIME SPENT IN

DIFFERENT FLIGHT CONDITIONS

Flights from New York	Climb	Level flight	Descent	Landing approaches
One flight to San Francisco	8.7	81.6	8.1	1.6
Total flights to San Francisco	11.2	74.2	12.0	2.6
To Chicago	11.7	70.1	13.4	4.8
To Kansas City	9.5	72.9	14.6	3.0
Total flight time	11.0	73.1	12.8	3.1

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TABLE IV

FREQUENCY DISTRIBUTIONS OF MAXIMUM AIRSPEEDS

FOR VARIOUS FLIGHT CONDITIONS

Equivalent airspeed (mph)	Frequency (climb)	Frequency (level flight)	Frequency (descent)
165 - 170	1		
170 - 175	3		
175 - 180	11		
180 - 185	22		
185 - 190	18	3	
190 - 195	11		
195 - 200	13		
200 - 205	13	3	
205 - 210	25	10	
210 - 215	8	20	
215 - 220	8	36	
220 - 225	1	26	2
225 - 230	6	114	1
230 - 235	3	54	1
235 - 240	4	175	1
240 - 245		134	1
245 - 250	1	183	1
250 - 255	2	76	6
255 - 260		103	4
260 - 265	2	36	8
265 - 270		40	14
270 - 275		3	18
275 - 280		3	18
280 - 285			21
285 - 290			15
290 - 295			16
295 - 300			15
300 - 305			17
305 - 310			10
310 - 315			3
315 - 320			4
320 - 325			2
Totals	152	1019	178

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TABLE V

FREQUENCY DISTRIBUTIONS OF MAXIMUM MACH NUMBERS

FOR VARIOUS FLIGHT CONDITIONS

Mach number	Frequency (climb)	Frequency (level flight)	Frequency (descent)
0.23 - 0.24	1		
.24 - .25	4		
.25 - .26	5	1	
.26 - .27	5		
.27 - .28	10		
.28 - .29	18		
.29 - .30	19	1	
.30 - .31	16		1
.31 - .32	14		1
.32 - .33	18	1	1
.33 - .34	13		1
.34 - .35	7		1
.35 - .36	6	9	3
.36 - .37	7	16	4
.37 - .38	4	24	6
.38 - .39	2	49	11
.39 - .40	2	96	11
.40 - .41		131	12
.41 - .42		197	16
.42 - .43	1	183	19
.43 - .44		150	24
.44 - .45		115	13
.45 - .46		28	17
.46 - .47		13	10
.47 - .48		4	7
.48 - .49			14
.49 - .50			2
.50 - .51			3
. . . .			
.53 - .54			1
Totals	152	1019	178

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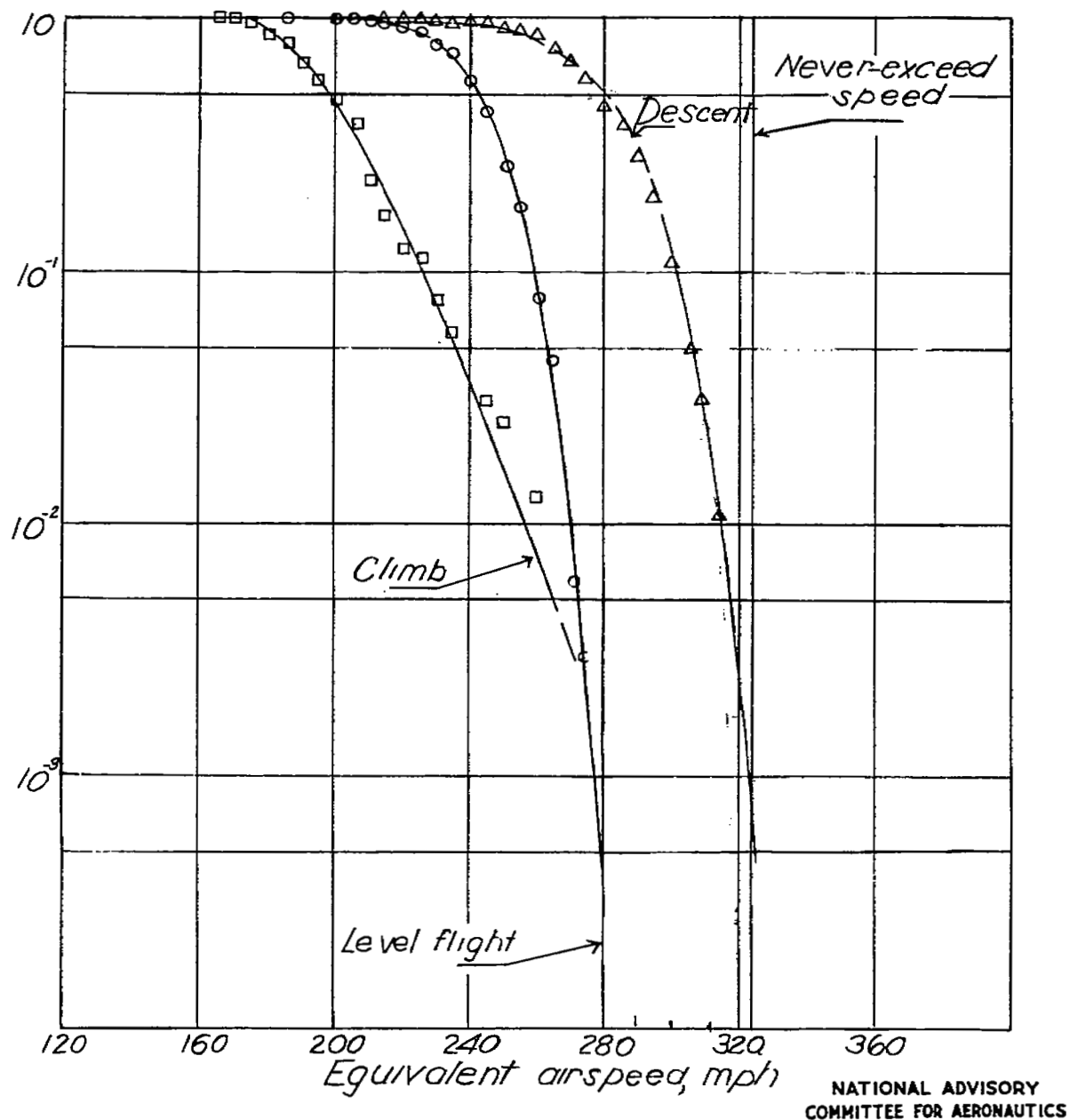COMMITTEE FOR AERONAUTICS
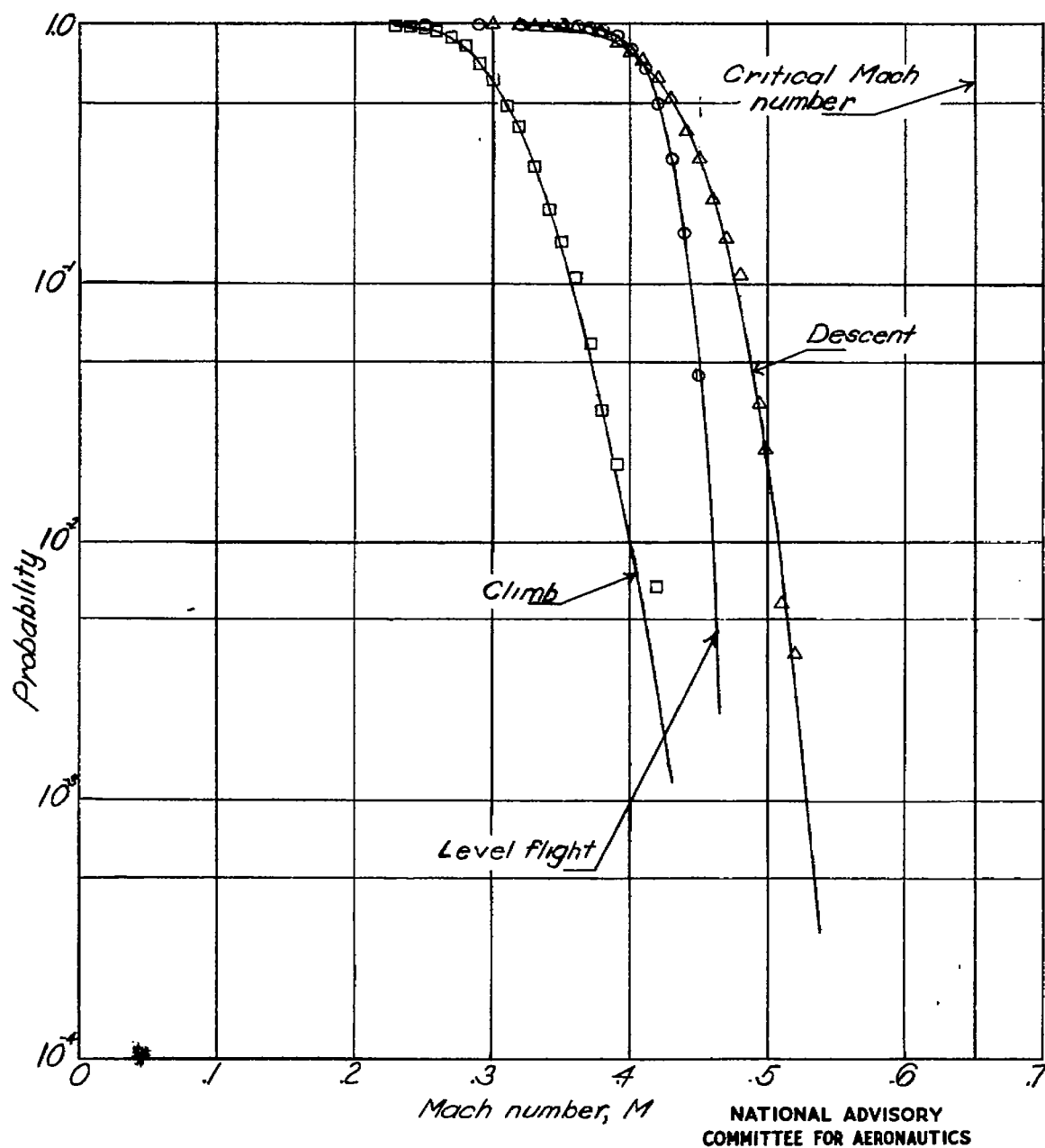
Figure 1 - Probability of exceeding a given value of airspeed

Figure 2 -Probability of exceeding a given value
of Mach number

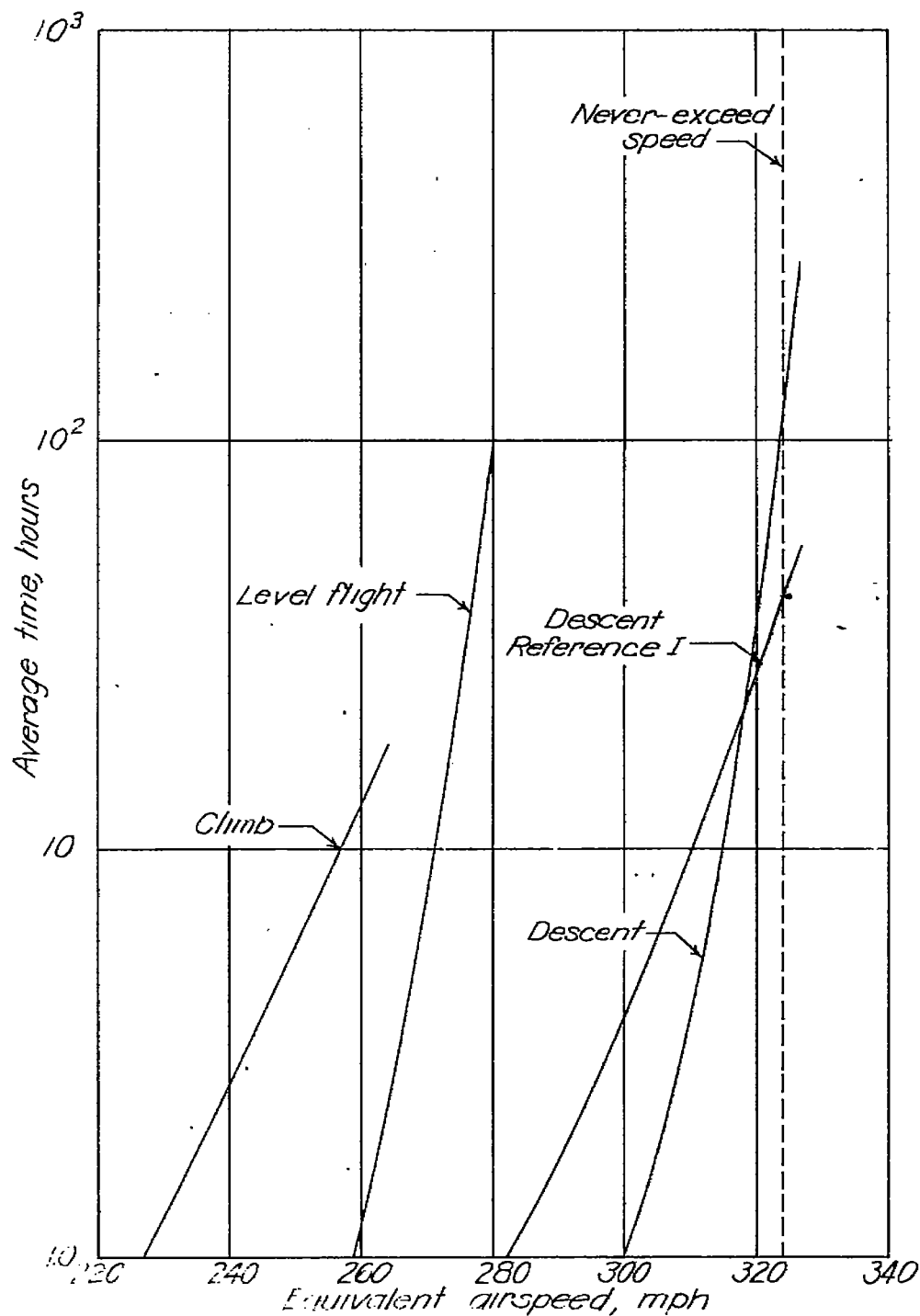Figure 3.- Average time required to exceed a given
value of airspeed.
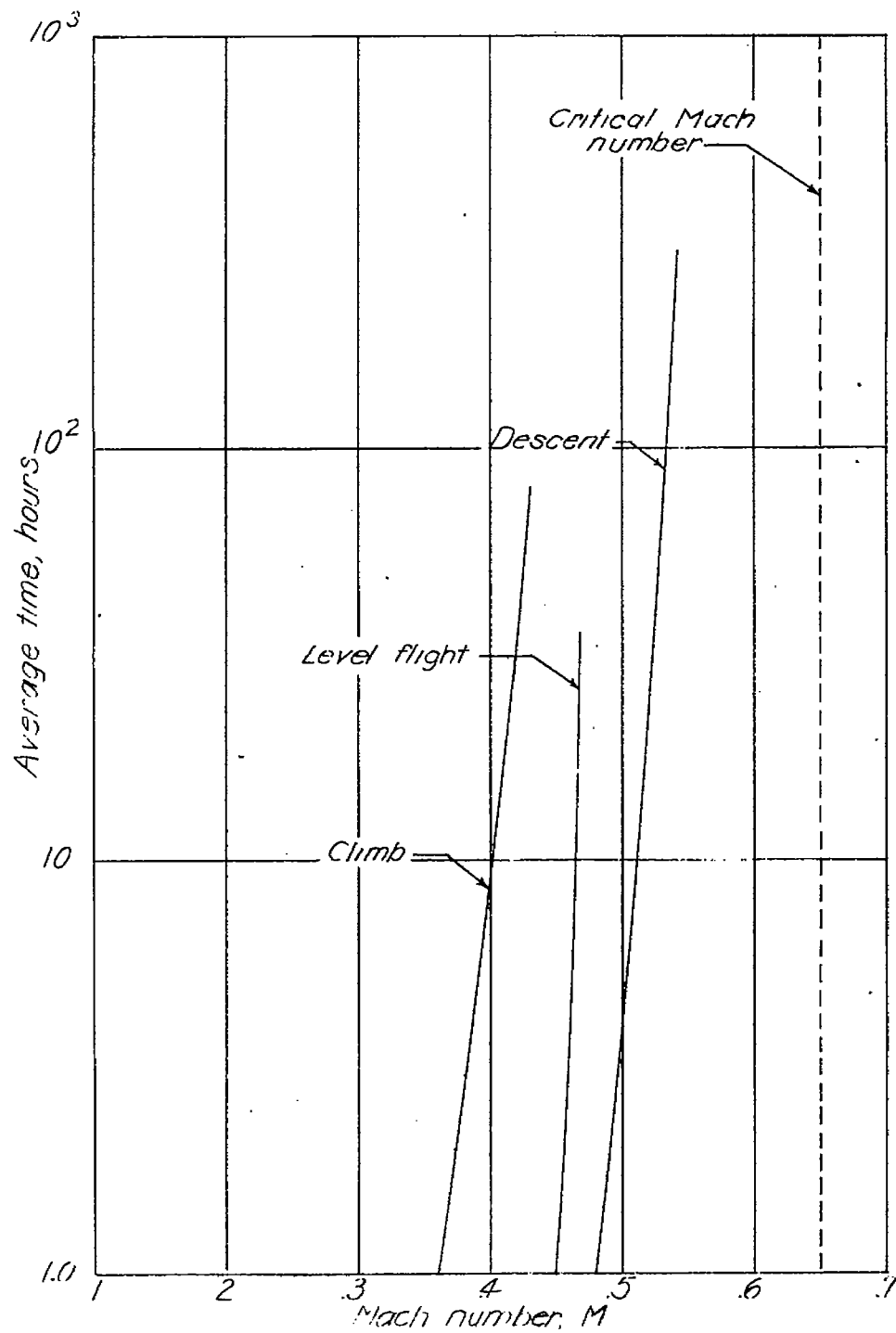
Figure 4.- Average time required to exceed a given value of Mach number.
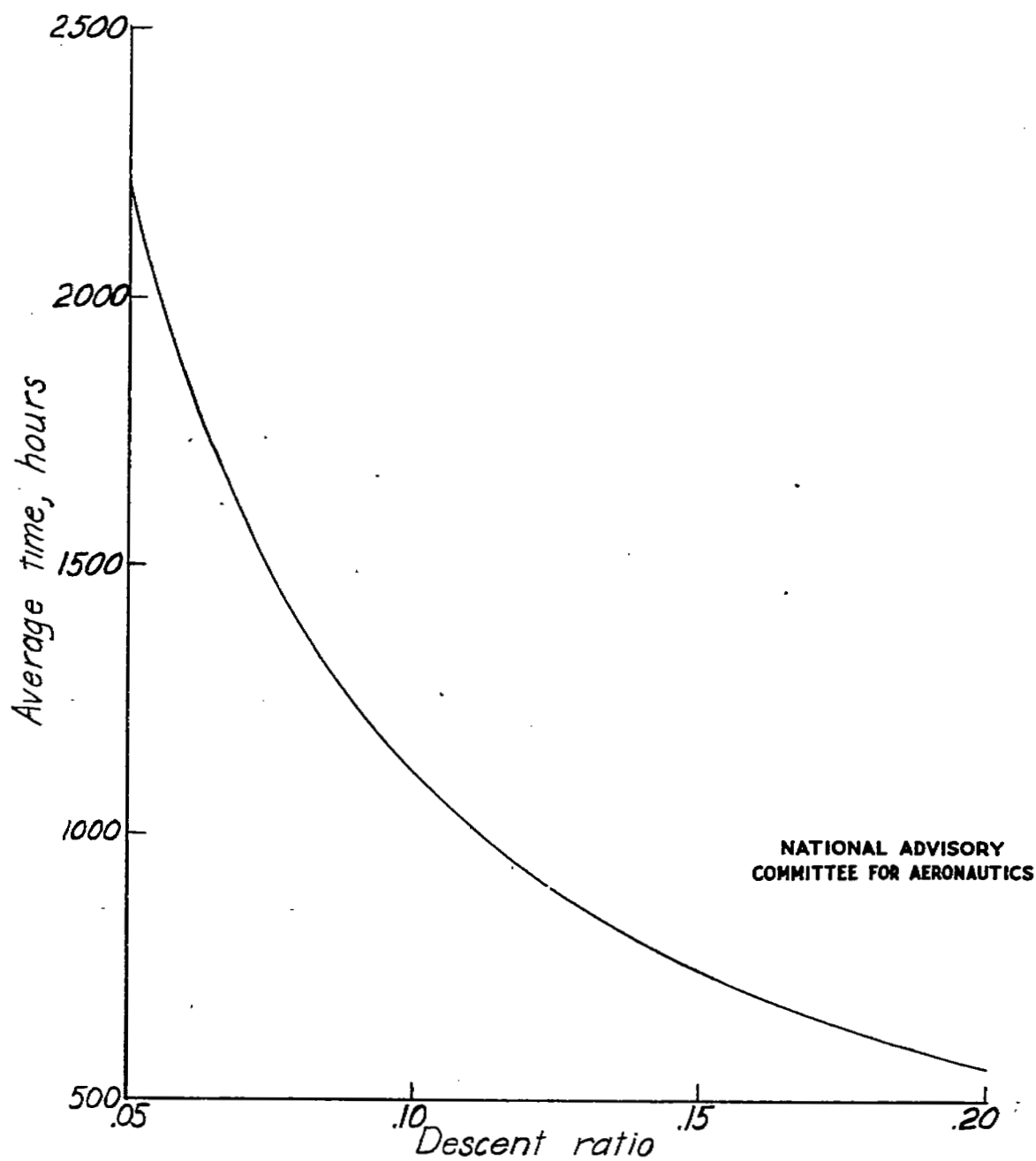
Figure 5 —Average flight time required to exceed a
speed of 324 miles per hour as a function of
descent ratio